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# (Invited) Thermo-Chemo-Mechanical Response of Solid Oxide Cells during Reduction and Cooling

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## Abstract

Thermal expansion mismatch among the materials used in a Solid Oxide Cell (SOC) generates in-plane strain within the SOC layers during the cooling process following sintering. These residual stresses induce cell curvature for asymmetric cells, challenging the stacking process, but more importantly they may also result in more fragile cells. Furthermore, the composite nature of some of the layers results in the development of local micro-strain in each constituent phase of the composite.

Both types of strain undergo major changes upon heating and reduction of the NiO-containing fuel electrode, and upon subsequent temperature changes during dynamic operation. Surprisingly fast deformation is observed upon reduction causing relaxation of residual stresses at a rate that is  $\sim 10^4$  times faster than creep during operation. The origins of this newly discovered chemo-mechanical response, termed accelerated creep, are discussed.

To assess and optimize the reliability of SOC during operation, the stress field and its thermo-chemical and temporal evolution must be known. In this work the stresses are measured in-situ before, during and after reduction by use of X-ray diffraction. Two different techniques are used to measure the stresses (elastic strains): i) The biaxial stresses in the cell plane are determined from the variation in spacing between lattice planes as a function of the angle of the lattice plane normal to the cell plane, and ii) the micro-strain is assessed from the widening of the Bragg peaks due to local stress. Utilizing diffraction peaks from different phases of the Ni(O)-YSZ/YSZ half-cell it is possible to determine both the in-plane stress at different SOC layers as well as the microstrain in each constituent phase of the composite Ni(O)-YSZ support layer.

As an example, the evolution of the in-plane stress in the YSZ electrolyte layer upon thermo-chemical conditioning (heating to 700 °C, reduction, and subsequent cooling to 25 °C) of the Ni(O)-YSZ/YSZ half-cell is shown in the Figure. The compressive stress in the electrolyte layer decreases with increasing temperature, due to the larger thermal expansion coefficient of the NiO-YSZ layer compared to YSZ. Very fast and nearly complete stress relaxation was observed upon reduction of the NiO-YSZ support. Compressive stress builds up again in the electrolyte upon cooling, but at a slightly slower rate.

The residual stresses of the two above-mentioned types i) and ii) have been measured in the YSZ electrolyte and Ni(O)-YSZ support layer as a function of temperature for different reduction temperatures. Furthermore, the stresses in the half-cell are assessed by use of a macroscopic finite element model, taking into account the elastic response and creep of each layer. The local stresses in the different phases of the Ni-YSZ composite are modelled by use of a 3D microstructural reconstruction combined with finite element modeling.

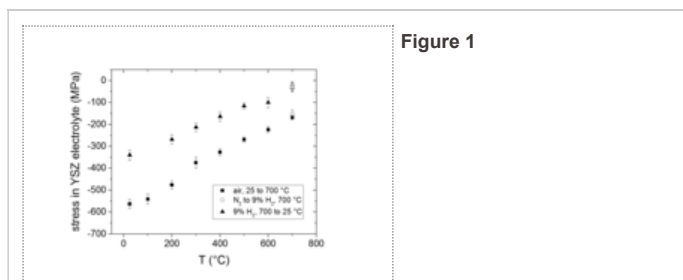


Figure 1

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